DOCUMENT RESUME

ED 330 710 TM 016 278

AUTHOR Lindsay, Jean S.
TITLE The "Chaos" Pattern in Piaget's Theory of Cognitive Development.
PUB DATE Feb 91
NOTE 21p.; Paper presented at the Annual Meeting of the Eastern Educational Research Association (14th, Boston, MA, February 18-22, 1991).
PUB TYPE Speeches/Conference Papers (150)

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS *Child Development; Children; Comparative Analysis; *Computer Science; *Piagetian Theory
IDENTIFIERS *Chaos Theory; Iterative Methods; *Nonlinear Models

ABSTRACT

Piaget's theory of the cognitive development of the child is related to the recently developed non-linear "chaos" model. The term "chaos" refers to the tendency of dynamical, non-linear systems toward irregular, sometimes unpredictable, deterministic behavior. Piaget identified this same pattern in his model of cognitive development in children. Piaget hypothesized that development is not a linear accumulation of discrete units of knowledge. Rather, he believed that periods of relative stability exist, which are necessarily followed by change, with a return to stability at a higher level of equilibrium. Piaget's notion of self-regulatory assimilation-accommodation is explicated. Attraction to the strange in the equilibrium process and iterative processes of cognition, both forwarded by Piaget, also fall into line with the chaos theory. Recent advances in computer technology have made it possible to simulate the behavior of complex systems, and as a result, the chaos model returned the physical sciences to the ideas of information theory. Using these tools, it may be possible to make sense of the aspects of Piaget's model that can not be supported using linear research models. A 27-item list of references is included. (TJH)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

ED330710

U.S. DEPARTMENT OF EDUCATION
Office of Educational Research and Improvement
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)

☑ This document has been reproduced as received from the person or organization originating it.

☐ Minor changes have been made to improve reproduction quality.

• Points of view or opinions stated in this document do not necessarily represent official OERI position or policy.

"PERMISSION TO REPRODUCE THIS MATERIAL HAS BEEN GRANTED BY

JEAN S. LINDSAY

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

THE "CHAOS" PATTERN IN PIAGET'S THEORY OF COGNITIVE DEVELOPMENT

Jean S. Lindsay, Ph.D.
17 Farmington Dr.
Charlottesville, VA 22901

Paper presented at the Eastern Educational Research Association's Annual Conference in Boston, Massachusetts, February 1991

TM016278

BEST COPY AVAILABLE

THE "CHAOS" PATTERN IN PIAGET'S THEORY OF COGNITIVE DEVELOPMENT

The purpose of this paper is to relate Piaget's theory of child cognitive development to the nonlinear "chaos" model recently developed by scientists. The term "chaos" was coined by scientists to refer to the tendency of dynamical, nonlinear systems toward irregular, sometimes unpredictable, yet deterministic behavior. Scientists from many different disciplines have found a similar pattern in everything from ecology to economic systems. Piaget identified this same pattern in his model of cognitive development in children.

Recent advances in computer technology have made it possible for scientists to simulate the behavior of complex systems. Thus they have been able to "see" the amazing complexity generated by simple iterative formulas. Scientists have finally discovered what Piaget grasped intuitively, i.e.,the order that exists in the seemingly random behavior of natural systems. This paper calls for researchers to take a new look at Piaget's in light of the nonlinear "chaos" model.

THE "CHAOS" PATTERN IN PIAGET'S THEORY OF COGNITIVE DEVELOPMENT
February 1991

INTRODUCTION

In years past, Piaget's theory of cognitive development was criticized by researchers who relied on cross-age correlations as a method of testing the validity of his findings. One reason for the failure to support Piaget's theory was that researchers favored linear models that reflected only the steady states of complex systems like that of cognitive development. Because most researchers relied on averages of groups of subjects, the upward curve of cognitive development was smoothed out and failed to show abrupt transitions and individual differences (McCall, 1979).

For years researchers have struggled with the limitations of linear models when studying the behavior of complex systems Gleick, 1987). Linear models work well when the goal is to study a system's behavior under controlled conditions. However, when the goal is to describe a system's behavior in its natural environment, the outcome is much less satisfactory. The cognitive development of children is one of those dynamic systems that constantly interacts with its environment and thus is neither simple or orderly in its behavior.

Piaget believed that the cognitive development of children is not continuous and linear, but rather proceeds in stages that are discontinuous and swing between stability and change. Linear models are capable of measuring the degree of relationship between variables only when they are correlated, that is, as one variable increases, the other increases proportionately. Thus

researchers over-reliance on simple cross-age correlations has lead to a picture of the consistencies of child development while ignoring the transitions and changes (McCall, 1979).

Until very recently scientists had few tools with which to study nonlinear behavior. However, now scientists have developed a nonlinear model that describes the seemingly random, yet orderly, behavior of complex natural systems. Scientists have already used this model to study everything from the dynamics of earthquakes to economic markets (Prigogine and Stengers, 1984; Gleick, 1987; Briggs and Peat, 1989; Bak and Chen, 1991). It holds promise for studying other systems as well.

PURPOSE

The purpose of this paper is to describe Piaget's theory of child cognitive development and to relate it to the nonlinear "chaos" model. A second purpose is to argue that features of Piaget's model that could not be supported using linear research models might begin to make sense in light of the "chaos" model.

The term "chaos" was coined by scientists to refer to the tendency of dynamical, nonlinear systems toward irregular, sometimes unpredictable, yet deterministic behavior. For example, May (1976) used a computer to simulate the growth of a fish population. He experimented with hundreds of parametrical values and found that the higher the parameter, the greater the degree of nonlinearity.

When the parameter was low, the population reached and maintained a steady state. However, when the parameter was high, the fish population begin to fluctuate wildly. When time series

was used to display data, it showed first a steady state represented by a straight line, then the line split and began to move back and forth between two or more points and finally the line begins to move up and down chaotically. However, there was a tendency for the fish population to return to the steady state of the system.

Scientists from many different disciplines begin to discover dynamic systems that displayed the characteristic "chaos" pattern. It is important to note that even though the term "chaos" implies random disorder, scientists have found a surprising order in seemingly chaotic behavior (Gleick, 1987).

RATIONALE

Models developed by scientists and mathematicians have frequently been adapted to new contexts. One example of this process is the information theory model, first developed by a mathematician (Shannon and Weaver, 1949). The technical term 'information' is defined as any event that makes a difference in some later event (Bateson, 1972).

The major tenet of information theory, based on the Second Law of Thermodynamics, held that the universe has a tendency to become increasingly disorganized and to slide toward total collapse or entropy. From this law Bertalanffy (1968) developed general systems theory which became a model for studying the behavior of complex systems. General systems theory held that a change in one part of a complex system will reverberate throughout the whole system. Thus any change would threaten the

system with disintegration if it were not for the tendency of complex systems to return to a steady state of equilibrium.

A complex system is one made up of a large number of parts that interact in a dynamic way (Simon, 1981). This definition holds for systems as widely disparate as the ecology of a pond or the organizational behavior of a large bureaucracy. Thus researchers found general system theory useful in studying many different kinds of complex systems.

Piaget borrowed the concept of equilibrium from physics and biology and modified it to apply to human intelligence (Ginsburg and Opper (1988). When applied to intellectual processes equilibrium refers to a process of balance and harmony between the system and its environment. Piaget was a trained biologist and was familiar with information theory. Thus he chose a different path for studying the development of cognition in children from those experimental psychologists who behavior was learned.

The "chaos" model returned the physical sciences to the ideas of information theory. The notion that information is a difference that influences later events is closely related to a key concept of chaos theory. This concept is called "sensitive dependence on initial conditions" often called "the Butterfly Effect--the notion that a butterfly stirring in Peiking can transform storm systems in New York." (Gleick, 1987, pg. 8). Thus very minor disruptions in one part of a system can result in major changes in the system as a whole.

PIAGET'S THEORY OF COGNITIVE DEVELOPMENT IN CHILDREN

Piaget's original purpose in studying child development was to discover the similarities between biological and cognitive adaptation and the way they progress through successive stages of growth (Atkinson, 1983). Scientific theory, particularly cybernetics, played a large part in the development of Piaget's theory. His model of cognitive development was that of an open system in which the organism constantly interacts with the environment.

Piaget believed that cognitive systems like other open systems had self-regulating mechanisms that permitted them to adapt to changes without becoming increasingly unstable and finally disintegrating (Gallagher, 1977). Accordingly, he believed that developmental reorganization or equilibration is the self-regulating mechanism that allows children to progress to higher levels of equilibrium throughout development (Ginsburgh & Opper, 1988).

Piaget derived his notion of equilibrium from Waddington's (1957) concept of 'homeorhesis.' Waddington defined homeorhesis as a tendency of a system towards a certain kind of equilibrium, which is restored after a disturbance. Thus this kind of equilibrium does not maintain homeostasis but instead centers the system on a direction or pathway of change (Atkinson, 1983). Prigogine and Stengers report that "Waddington introduced the concept of 'chreod' to describe the stabilized paths of development produced as a result of the double imperative of

flexibility and security (1984, p. 172).

Piaget viewed cognitive development as a creative and ongoing process in which the structures of earlier stages serve as the scaffolding for the next stage. Therefore, a previous structure can be assimilated into a new one without destroying the old one (Gallagher, 1977). However, although these earlier structures are conserved, they do not remain the same but are transformed during the transition from one stage to the next.

Thus during the process of development there is always some kind of transformation taking place, but at the same time, there is always something being conserved or unchanged (Piaget, 1977). In working with models of traffic, sandpiles and earthquakes, scientists have found them to be similar in the sense that elements are always conserved. The conservation of elements is an important feature of many systems that naturally self-organize (Bak and Chen, 1991).

Transformation and conservation are inseparable because with one there would be constant change and ultimate disorder and with the other the system would be unchanging and static. So there must be both transformation and conservation to prevent the system from swinging too far towards either disintegration or stagnation.

The dual mechanisms of assimilation and accommodation allow the child to incorporate new concepts into the existing framework. For example, whenever an action gives rise to assimilation it is met with accommodation. According to Piaget,

"There is a bipolarity, in which the subject is assimilating the object into his schemes and at the same time accommodating his schemes to the special characteristics of the object. And in this bipolarity and sharing of processes, there is already a factor of equilibration between assimilation and accommodation." (Piaget, 1977, p.4) Through a succession of assimilations and accommodations, cognitive development progresses through higher and higher levels of equilibrium. Thus, each new cognitive stage is made up of output from the previous stage and becomes the input to the next stage in an ongoing process.

Perhaps no part of Piaget's theory has generated more controversy than the notion that cognitive development progresses through a sequence of stages (For example, Hunt, 1977; Gelman and Baillargeon, 1983). Yet this notion is central to Piaget's theory. Piaget did not believe that cognitive development is merely the slow accumulation of isolated and unconnected entities. Rather he believed that each stage has a unified structure that is qualitatively different from any other stage. Piaget believed that all children pass through the same sequence of stages even though the ages at which they pass from one stage to another may vary from one child to the next. He identified and described four stages of development in all:

1. Sensorimotor intelligence (birth to 14-18 months): This stage is characterized by perceptual and motor development. Toward the end of this stage, the child becomes aware of the permanence of objects.

2. Preoperational thought (2-7 years): Object permanence sets the stage for representation to develop, so that the child understands that objects can be classified and grouped. This allows the child to use words to stand for concepts and thus allows the rapid development of language.

3. Concrete operations (7-11 years) The child's view of reality changes radically because he or she is able to go beyond the appearance of objects to discover underlying principles and how objects relate to one another. However, the child's thinking is tied to objects only when they are physically present.

4. Formal operational thought (12 years and beyond): Abstract thinking is now possible and the child becomes capable of solving hypothetical problems even in areas in which he has had no direct experience (Lindsay, 1988).

SIMILARITIES BETWEEN PIAGET'S MODEL AND THE CHAOS MODEL

Nonlinearity

This brief outline of Piaget's model of cognitive development has highlighted some of the most important features of his theory. At this point the parallels between his theory and that of "chaos " should become clearer. Piaget hypothesized that the developmental process is not one of discrete units of knowledge accumulated linearly over time. Rather he believed that there are periods of relative stability followed by a gradual build-up of change to a period marked by multiple changes with a return to stability at a higher level of equilibrium. Indeed, this process takes place even before birth. Prigogine

and Stenger report "when embryological development is observed on film, it is possible to 'see' jumps corresponding to radical reorganizations followed by periods of more 'pacific' quantitative growth." (1984, p. 171) This nonlinear process is strikingly similar to that of the natural systems observed by scientists studying "chaos".

Indeed nonlinearity is a key attribute of "chaos" theory. Scientists have known for a long time that nonlinearity existed. However, they were used to thinking of nonlinearity in dynamic systems as an exception. For example, from the time of Galileo, scientists modeled the behavior of a pendulum as if it had regular periodic movements. In fact they were modeling a regularity that didn't exist. Thus scientists were used to disregarding friction and air resistance when studying the dynamics of pendulums (Gleick, 1987). However, a few scientists were becoming aware that it is impossible to disregard those factors that produce nonlinearity. These scientists found that the solvable linear systems were the exception and that disorderly nonlinear systems were the rule.

However, this finding created a real problem because nonlinearity expressed relationships that were not strictly proportional, that is, as one variable changed the other changed proportionally. Scientists had developed few tools for dealing with nonlinearity. Models of linear systems can be manipulated, i.e., they can be taken apart and put together again. Linear problems were solvable, while nonlinear systems were generally

not solvable. However, as scientists began to experiment with simple equations, the nonlinear behavior of dynamical systems became clearer.

Self-similarity

In studying the development of cognition in children, Piaget discovered patterns that were similar at both macro and micro levels of development. For example, he found that in the construction of new structures a child goes through much trial and error that requires self-regulation. Piaget believed "These self-regulations come into play at all levels of cognition, including the very lowest level of perception." (1977, p. 10)

Furthermore, he found in every interaction of the child's mind with objects in the environment there is assimilation of that object to his mind and there is accommodation of the child's mind to the object. As assimilation-accommodation occurs over and over again, there is a gradual change of Mind-1 (a given developmental level) to Mind-2 (of some arbitrarily higher level) and at this higher level there is assimilation of the environment to mind and an accommodation of the mind to its environment (Flavell, 1985).

Self-similarity was also inherent in Piaget's notion that phylogeny recapitulates ontogeny (Piaget, 1970). He was intrigued with the possibility that assimilations and accommodations might have operated at the evolutionary level as well. He hypothesized that the developmental stages of thinking in the child mirrored the evolution of thinking from ancient times to the present. Thus

the thinking of a four-year would be like that of a Neanderthal adult and the logical thinking of the adolescent would reflect mankind's great breakthrough into scientific thought. This notion suggested a powerful unity of the human mind that appealed to Piaget in his quest for universal laws of logic (Cohen, 1983).

Self-similarity has also been found to characterize the behavior of dynamic non-linear systems. For example, Mandlebrot (1977), a mathematician, studied the pattern of cotton market prices from 1900 onward. He looked for patterns not at one scale or another but across every scale. He knew that changes in cotton prices did not fit the familiar bell-shaped curve of the normal distribution but when he put the numbers into the computer, he realized that they did fit from the standpoint of scaling or self-similarity. In other words the pattern was one of macro scales to micro ones; that is, the pattern for daily prices fit perfectly the pattern of monthly prices.

This pattern of self-similarity can be seen in many of the systems that make up the human body from the vasculatory system to the respiratory system (Prigogine and Stengers, 1984). Thus, the parts of these systems have the same structure as the whole of the system just as trees have limbs made up of branches. Until recently anatomists were accustomed to studying these systems by breaking them down to their smallest parts rather than looking at the system as a whole. However, a decade after Mandelbrot discovered the scaling pattern in economic systems, biologists began to note these same patterns in human systems

(Gleick, 1987).

Recently evidence supporting Piaget's description of cognitive development at the micro level has been found. Scientists have discovered that consciousness appears to be a recursive process in which the brain plans for each future action on the basis of past action. An act of perception is a step in a process by which brains grow, reorganize themselves and reach into their environment to change it to their own advantage (Freeman, 1991). This process is remarkably similar to Piaget's assimilation-accommodation theory of cognitive change.

Strange Attractors

Equilibration is a self-regulating mechanism in Piaget's theory of cognitive development that prevents the system from swinging too far toward the opposing poles of either stability or change. If too much change took place too rapidly the system would be threatened with disintegration. However, if no change took place the system would stagnate and fail to develop. Thus the system is attracted to a state of equilibrium that protects it from either of these two extremes.

The tendency of systems to return to a steady state has been observed in other natural systems. For example, Feigenbaum (1978) found that no matter what the starting point, animal populations had a tendency to be attracted to the steady state in the cycle. When traditional time series were used to display data, it showed the characteristic chaos pattern of first a steady state, then the bifurcations and oscillations between two

points, and finally, chaos. When this same data was shown in phase space it was possible to view the trajectories of the system. Feigenbaum and others found that these trajectories traced a pattern around two points that formed a pattern much like a butterfly. He called these points "strange attractors."

Iterative Processes

The iterative process observed by scientists in many natural systems is also a feature of Piaget's model of cognitive development. Piaget observed the iterative process when a new cognitive stage preserved the structures from a previous stage, then transformed them into a new stage. Thus a feedback loop was created whereby the output from one stage served as the input for the next.

This iterative process was also found to be an important feature of the "chaos" pattern. For example, May (1976)) used changes in the fish population of an imaginary pond to demonstrate that the simplest nonlinear iterative process could show very complicated behavior. He developed a simple model based on the equation $y = rx(1-x)$ where y equals next year's population, x equals this years population, and r equals the rate of growth. (1-x) keeps x in bounds because as x rises (1-x) falls. Thus because the output from one year serves as input for the next year a feedback loop is created in iterative process that increases exponentially over time.

DISCUSSION

With the advent of "chaos" theory, researchers have begun to

question the validity of many studies based on a linear model of human iterations (for example, Cziko, 1989; Cronback, 1989; Lindsay, 1990). They argue that linear models are inappropriate for studying human interactions that are highly dynamic and unpredictable. Cziko advocates descriptive studies that would improve our understanding of social and cognitive development. Indeed, he points to research in child development evolving out of a Piagetian perspective as a desirable alternative to research based on linear models. He writes that research that focuses on individual children is much more compatible with "chaos" theory "because it provides qualitative descriptions of cognitive functioning and development, which make possible an appreciation of the mental processes and problem-solving strategies used by children in educational settings" (1989, p. 24).

Very early in his career Piaget used the standardized test as a method of studying children's cognitive development. However, instead of focusing on correct responses, he concentrated on analyzing the mistakes that children made in answering questions on these tests. He questioned his subjects to find out why they made a particular reply. Soon he discovered that children had a very different way of reasoning than did adults (Cohen, 1983).

Piaget rejected standardized tests as a tool for studying cognitive development because he believed that such tests failed to capture the underlying processes in children's thinking (Ginsburg & Opper, 1988). Standardized tests in particular

measure only the continuities of child development. When a developmental function is continuous, the fundamental nature of a given attribute does not change over time. For example, as a child ages, his height will increase more or less proportionally. However, when development is discontinuous, its behavioral character differs from one stage to the next (McCall, 1979).

Piaget chose the clinical interview technique as a means of gaining access to children's cognitive processes. This method, devised by Freudian psychoanalysts, was regarded as sloppy and "unscientific" by experimental researchers. However, in expert hands, it is neither, but rather "the most useful and valid method currently available for the study of thinking" (Ginsburg & Opper, 1988, p. 252).

If Piaget had adopted the prevailing research methodology of averaging across subjects, it might have blurred his vision of child cognitive development. Thus he might not have discovered the swings between stability and change that characterize childrens' development. Fortunately he had developed painstaking patience in his training in biology and thus studied the behavior of children over a prolonged period of time. As a result he noted the most minute changes in children's thinking and, in this way, discovered their hidden cognitive structures.

Recent advances in computer technology have made it possible for scientists to simulate the behavior of complex systems. Thus they have discovered the hidden structure in nature that Piaget found through painstaking observation over a long period of time.

It is certain that Piaget would have been intrigued with scientists' discovery of the order that exists in the seemingly random behavior of natural systems. Indeed, Piaget suggested that the dynamism of cognitive development could be captured by the use of concepts derived from computer programming analogies; however, he never attempted to do so himself (Atkinson, 1983).

It has been the purpose of this paper to take a fresh look at Piaget's work in the light of "chaos" theory. This nonlinear model has illuminated our understanding of the behavior of dynamic systems in nature. As one scientist put it, "You don't see something until you have the right metaphor to let you perceive it." (Shaw, as quoted in Gleick, 1987 p. 262). Piaget had the right metaphor years ahead of his colleagues. Now scientists are finally beginning to understand concepts that he grasped intuitively.

In urging his colleagues to study change in children's early development as vigorously as they do stability, McCall wrote, "we must look beyond specific behaviors and explore the common functions of diverse actions, wherein I suspect Nature has cloaked the order we seek." (1979, p. 218) The nonlinear "chaos" model may allow us to do just that.

REFERENCES

Atkinson, C. (1983). Making sense of Piaget. London: Routledge & Kegan Paul.

Bak, P, & Chen, K. (1991, January). Self-organized criticality. Scientific American, 46-53.

Bateson, G. (1972). Steps to an ecology of mind. New York: Random House, Inc.

Bertalauffy, L. (1968). General system theory. New York: George Braziller.

Briggs, J., & Peat, F. D. (1989). Turbulent mirror: An illustrated guide to chaos theory and the science of wholeness. New York: Harper Row.

Cohen, D. (1983). Piaget critique and measurement. New York: St. Martin's Press, Inc.

Cronbach, L. (1988). Playing with chaos. Educational Researcher, 46-49.

Cziko, G. A. (1989, April). Unpredictability and indeterminism in human behavior: Arguments and implications for educational research. Educational Researcher, 17-25.

Flavell, J. H. (1985). Cognitive development (2nd ed.). Englewood Cliffs, NJ: Prentice Hall, Inc.

Feigenbaum, M. J. (1978). Quantitative universality for a class of nonlinear transformations. Journal of Statistical Physics, 19(25).

Freeman, W. J. (1991, February). The physiology of perception. Scientific American, 78-85.

Gallagher, J. M. (1977). Piaget's concept of equilibration: Biological, logical, and cybernetic roots. In M. H. Appell and L.S. Goldberg (Eds.), Topics in cognitive development: Vol. 1. Equilibration: Theory, research, and application (pp. 21-33). New York: Plenun Press.

Gelman, R., & Baillargeon, R. (1983). A review of some Piagetian concepts. In P. H. Mussen (Ed.), Handbook of child psychology: Vol. III (pp. 167-230). New York: John Wiley & Sons.

Ginsburg, H. P., & Oppen, S. (1988). Piaget's theory of intellectual development (3rd ed.). Englewood Cliffs, NJ: Prentice Hall.

Gleick, J. (1987). Chaos: Making a new science. New York: Viking Penguin, Inc.

Hunt, J. M. (1977). Sequential order and plasticity in early psychological development. In M. H. Appel and L.S. Goldberg (Eds.), Topics in cognitive development: Vol. 1. Equilibration: Theory, research, and application. New York: Plenun Press.

Lindsay, J. S. (1989). Relationship of developmental disfluency and episodes of stuttering to the mergence of cognitive stages in children. Journal of Fluency Disorders, 14, 271-284.

Lindsay, J. S. (1989). "Chaos" theory: Implications for educational research. Paper presented at the annual meeting of the Eastern Educational Research Association.

Mandelbrot, B. (1977). The fractal geometry of nature. New York: Freeman.

May, R. M. (1976). Simple mathematical models with very complicated dynamics. Nature, 261, 459.

McCall, R. B. (1979). Qualitative transitions in behavioral development in the first two years of life. In M.H. Bornstein and W. Kessen (Eds.), Psychological development from infancy: Image to intention, (pp. 183-224). Hillsdale, NJ: Lawrence Erlbaum Associates, Publishers.

Piaget, J. (1970). Genetic epistemology. New York: Columbia University Press.

Piaget, J. (1977). Problems of equilibration. In M.H. Appel and L.S. Goldberg, Topics in cognitive development: Vol. 1. Equilibration: Theory, research, and application (pp. 21-32). New York: Plenum Press.

Prigogine, I., & Stengers, I. (1984). Order out of chaos. Toronto: Bantam Books.

Shannon, C. E., & Weaver, W. (1940). The mathematical theory of information. Urbana: University of Illinois Press.

Simon, H. (1981). The science of the artificial. Cambridge: The M.I.T. Press.

Waddington, C. H. (1957). The strategy of the genes. London: George Allen & Unwin.